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Strange b baryon production and lifetime in Z decays

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The ALEPH Collaboration

Abstract

In a data sample of approximately four million hadronic Z decays recorded with the ALEPH detector from 1990 to 1995, a search for the strange b baryon Ξ_b is performed with a study of Ξ-lepton correlations. Forty-four events with same sign $\Xi^-\ell^-$ combinations are found whereas 8.4 are expected based on the rate of opposite sign $\Xi^-\ell^+$ combinations. This significant excess is interpreted as evidence for Ξ_b semileptonic decays. The measured product branching ratio is $\mathrm{Br}(b \to \Xi_b) \times \mathrm{Br}(\Xi_b \to X_c X \ell^- \overline{\nu_\ell}) \times \mathrm{Br}(X_c \to \Xi^- X') = (5.4 \pm 1.1(\mathrm{stat}) \pm 0.8(\mathrm{syst}))\, 10^{-4}$ per lepton species, averaged over electrons and muons, with X_c a charmed baryon. The Ξ_b lifetime is measured to be $\tau_{\Xi_b} = 1.35^{+0.37}_{-0.28}(\mathrm{stat})^{+0.15}_{-0.17}(\mathrm{syst})$ ps.

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1 Introduction

Significant progress has been made in the last decade in the study of B mesons. The detailed experimental study of the production rates and properties of the b baryons is more recent, made possible with the advent of the LEP and Tevatron experiments.

The production rate of b baryons at LEP is measured [1] to account for about 12% of b hadrons, dominated by the lightest state Λ_b, produced either directly or from Σ_b or Σ_b^* decays. Indirect evidence for the Λ_b was reported by the LEP experiments [2] from the study of $\Lambda\ell^-$ and $\Lambda_c^+\ell^-$ correlations. Later, the Λ_b lifetime [3] and Λ_b polarization [4] were measured. Direct evidence for the Λ_b [5] in exclusive hadronic decays was reported recently and its mass determined.

The strange b baryons Ξ_b and Ω_b are expected to be produced in $Z\rightarrow b\bar{b}$ decays[1]. The production of Ξ_b is more abundant than Ω_b due to the lower number of constituent strange quarks in the Ξ_b. Ground state Ξ_b decays proceed as for Λ_b via weak decays. Following the same procedure used for the indirect search of Λ_b in hadronic Z decays, the Ξ_b baryons are searched for in the semileptonic decay channel, namely $\Xi_b \rightarrow X_c X\ell^-\overline{\nu}_\ell$ followed by[2] $X_c \rightarrow \Xi^- X$, using the charge correlation between the Ξ^- and the lepton as a tag. Therefore the signature for Ξ_b decaying semileptonically is the presence of same sign $\Xi^-\ell^-$ pairs. A first study of the production of strange b baryons in Z decays was recently published by the DELPHI collaboration [6].

2 The ALEPH Detector

The ALEPH detector and its performance are described in detail elsewhere [7]. In this section, only a brief description of the apparatus properties most relevant to this analysis is given. The critical elements are charged particle tracking, including especially the silicon vertex detector, particle identification with ionization energy loss (dE/dx), electron identification in the electromagnetic calorimeter and muon identification in the hadronic calorimeter supplemented by muon chambers.

Charged particles are tracked with three concentric devices residing inside an axial magnetic field of 1.5 T. Just outside the 5.4 cm radius beam pipe is the vertex detector (VDET) [8], which consists of double sided silicon microstrip detectors with strip readout in two orthogonal directions. The strip detectors are arranged in two cylindrical layers at average radii of 6.3 and 10.8 cm, with solid angle coverage of $|\cos\theta| < 0.85$ for the inner layer, and $|\cos\theta| < 0.69$ for the outer layer. The point resolution for tracks at normal incidence is 12 μm in both the $r\phi$ and z projections.

Surrounding the VDET is the inner tracking chamber (ITC), a cylindrical drift chamber with up to eight measurements in the $r\phi$ projection. Outside the ITC, the time projection chamber (TPC) provides up to 21 space points for $|\cos\theta| < 0.79$, and a decreasing number of measurements at smaller angles, with 4 space points at $|\cos\theta| = 0.96$.

The combined tracking system has a transverse momentum resolution of $\Delta p_t/p_t = 0.0006 \times p_t \oplus 0.005$ (p_t in GeV/c). For tracks with hits in both VDET layers the impact parameter resolution on a track of momentum p is 25 μm + 95 μm/p (p in GeV/c).

In addition to tracking, the TPC is used for particle identification by measurement of

[1] Throughout this paper, Ξ_b is used as a generic name for Ξ_b^0 and Ξ_b^-, Ξ_c for Ξ_c^0 and Ξ_c^+, B for B^+, B^0 and B_s mesons, and D for D^+, D^0 and D_s mesons. Charge conjugate modes are implied everywhere.

[2] X_c is used as a generic name for a charmed baryon which may give a Ξ hyperon in its decays: X_c is dominantly Ξ_c but may also be Λ_c^+, Σ_c or Ω_c.

the ionization energy loss associated with each charged track. It provides up to 338 dE/dx measurements, with a measured resolution of 4.5% for Bhabha electrons with at least 330 ionization samples. For charged particles with momenta above 3 GeV/c, the mean dE/dx gives a separation of approximately 3 standard deviations (σ) between pions and protons. At least 50 ionisation samples are required to get a dE/dx measurement; this occurs for 80% of charged tracks.

Electrons are identified by their shower shape in the electromagnetic calorimeter (ECAL), a lead-proportional chamber sandwich segmented into 15 mrad $\times$ 15 mrad projective towers which are read out in three sections in depth. The dE/dx measurement on the track, if any, gives an independent signature for electrons. Muons are identified from their pattern in the hadron calorimeter (HCAL), a seven interaction length yoke interleaved with 23 layers of streamer tubes; two double layers of muon chambers outside the HCAL give an additional signature for muons.

3 Origin of Ξ-lepton combinations in hadronic Z decays

There are five possible sources of Ξ-lepton combinations in hadronic Z decays :

$$\Xi_b \to X_c X \ell^- \overline{\nu}_\ell, \qquad X_c \to \Xi^- X \tag{1}$$

$$(\Lambda_b, \overline{B}) \to X_c X \ell^- \overline{\nu}_\ell, \qquad X_c \to \Xi^- X \tag{2}$$

$$b, c \to X_c X, \qquad X_c \to \Xi^- \ell^+ X \nu_\ell \tag{3}$$

$$\text{Accidental combinations} \tag{4}$$

$$\text{Fake combinations} \tag{5}$$

Process (1) is the signal and leads to same sign $\Xi^-\ell^-$ combinations. Process (2) also leads to same sign combinations. Process (3) leads to opposite sign $\Xi^-\ell^+$ combinations only. Accidental combinations arise when a Ξ^- baryon from fragmentation is paired with a lepton from the semileptonic decay of a c or b hadron. Fake combinations (5) occur when a misidentified hadron (fake lepton) is paired with a true Ξ^-, or a lepton from the semileptonic decay of a c or b hadron with a fake Ξ^- (spurious $\Lambda\pi$ combination with invariant mass compatible with the Ξ^- mass), or a fake lepton with a fake Ξ^-.

4 Strange b baryon candidate selection

4.1 The event sample

The analysis presented in this letter is based on about 4.2 million hadronic Z decays recorded with the ALEPH detector from 1990 to 1995 and selected as described in [9].

The Monte Carlo simulation is done with the JETSET 7.4 program using the LUND model [10] slightly modified to take into account the latest values of the decay branching fractions of c and b mesons and baryons. All the simulated events are processed through the chain of reconstruction and analysis programs used for the data. Five Monte Carlo data sets are used for this analysis, one for each process of section 3. For the signal, the simulated data consist of 40,000 decays $\Xi_b \to \Xi_c X \ell^- \overline{\nu}_\ell$ with no polarisation, of 20,000 decays with 100% Ξ_b polarisation, and of a third set with $\Xi_b \to \Xi_c \rho \ell^- \overline{\nu}_\ell$ for specific studies of four-body decays. For processes (2) and (3), different specific decay channels of Λ_b, B mesons, Λ_c^+ and Ξ_c giving a Ξ^- and a lepton have been generated, with at least 3000 events per channel. For processes (4), a set of events with a Ξ^- and a lepton in the same event hemisphere equivalent

to 12 times the data sample has been generated. The estimation of fake combinations has been done on the standard ALEPH Monte Carlo data set, equivalent to 5.6 million hadronic Z decays.

4.2 Ξ_b candidate selection

The event selection starts with the requirement of hadronic Z events where a Ξ^- is associated with a lepton in the same hemisphere with respect to the thrust axis. The lepton candidate selection is described in [11]. Electron and muon candidates are required to have a momentum greater than 3 GeV/c.

The Ξ^- candidates are reconstructed through their decay $\Xi^- \rightarrow \Lambda\pi^-$. The Λ candidates are reconstructed in the decay channel $\Lambda \rightarrow p\pi^-$, using a slightly modified version of the algorithm described in [12]. To reduce the combinatorial background, the two oppositely charged tracks are required to have a total momentum greater than 2.5 GeV/c and to form a vertex corresponding to a decay length of at least 5 cm from the interaction point. The dE/dx measurements of the two tracks, when available, are required to be within 3σ of those expected for a proton and a pion respectively. To reduce the possible contamination from other displaced vertices, the invariant mass of the two daughter tracks is required to be within 3σ of the Λ mass (σ is momentum-dependent, as described in [12], with an average value of 3 MeV/c^2) and incompatible with the $\gamma \rightarrow e^+e^-$ hypothesis ($M_{e^+e^-} > 15$ MeV/c^2). If the dE/dx information for the proton candidate is consistent with that of a pion, or if the dE/dx information is not available for the proton candidate, an additional cut to remove K^0_s's is applied ($|M_{\pi\pi} - M_{K^0_s}| > 10$ MeV/c^2, i.e. a 3σ cut around the K^0_s mass).

To reconstruct Ξ^- baryons, the selected Λ candidates are combined with a pion from the same hemisphere having a negative charge. The pion is required to have a transverse momentum between 0.09 and 0.2 GeV/c with respect to the $\Lambda\pi^-$ system, to eliminate most of the $\Lambda\pi^-$ combinatorial background. The $\Lambda\pi^-$ system is required to have a momentum greater than 3 GeV/c and a longitudinal momentum with respect to the event thrust axis greater than 2.5 GeV/c. The χ^2 probability of the $\Lambda\pi^-$ vertex fit must be greater than 1% and the $\Lambda\pi^-$ decay length with respect to the interaction point must be greater than 1.5 cm. Finally, the $\Lambda\pi^-$ system is required to satisfy $|M_{\Lambda\pi} - M_\Xi| < 23$ MeV/c^2, with $M_\Xi = 1321.3$ MeV/c^2 from [13] and where 23 MeV/c^2 is equal to three times the typical Ξ^- mass resolution.

Selected Ξ^- candidates are combined with an identified lepton from the same hemisphere if the angle between the Ξ^- and the lepton is less than 30°. The Ξ^- and the lepton are required to belong to the same jet.[3] The Ξ-lepton system is required to have an invariant mass between 2.5 and 5.0 GeV/c^2 ; this cut eliminates completely all combinations coming from semileptonic decays of charmed baryons.

Fig. 1 shows the $\Lambda\pi^-$ invariant mass distribution of the same sign $\Xi^-\ell^-$ and the opposite sign $\Xi^-\ell^+$ combinations after all selection cuts are applied except the $\Lambda\pi$ mass cut. A mass peak is seen in both distributions at the Ξ^- mass, with a clear excess of $\Xi^-\ell^-$ with respect to $\Xi^-\ell^+$ combinations. A fit to the two distributions (a Gaussian for the Ξ^- peak and a polynomial for the background) yields a mean value compatible with the nominal Ξ^- mass, and a width consistent with the Monte Carlo expectation (7.5 MeV/c^2).

[3] The jets are defined with the JADE algorithm [14] with $y_{cut} = 0.015$.

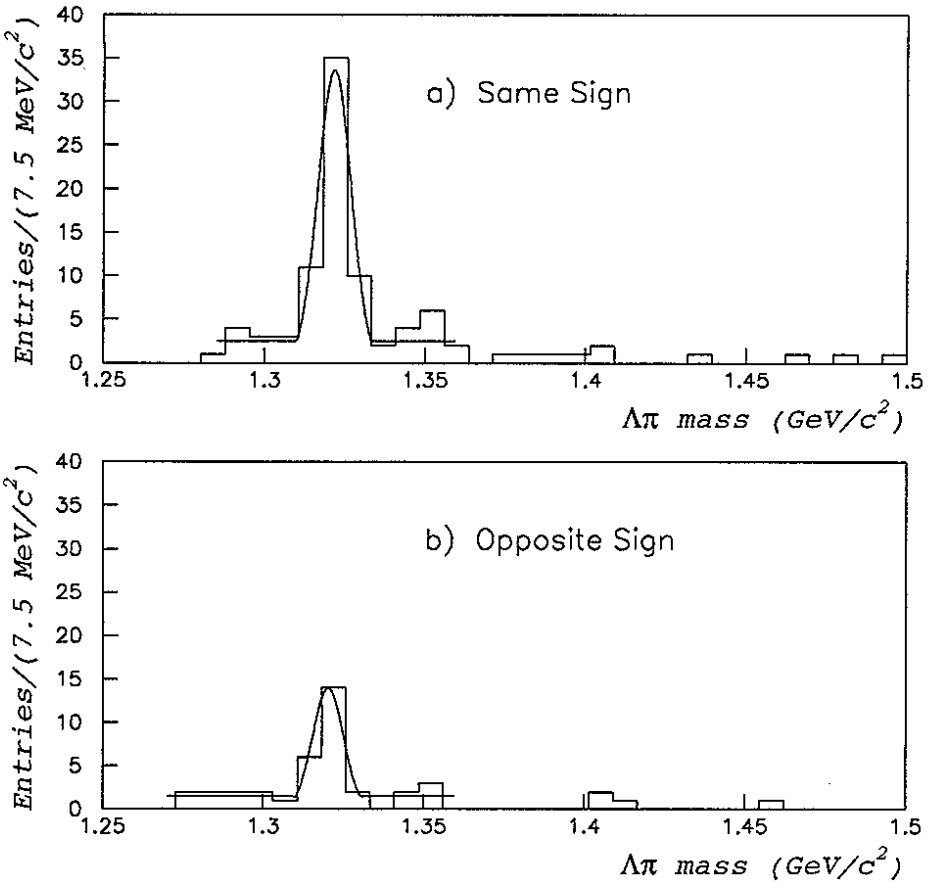

Figure 1: The $\Lambda\pi^-$ invariant mass distribution of (a) the same sign $\Xi^-\ell^-$ and (b) the opposite sign $\Xi^-\ell^+$ combinations. All selection cuts of section 4.2 are applied except the $\Lambda\pi^-$ mass cut. The curve is the result of a fit described in the text.

4.3 Improved Ξ_b selection with a discriminating variable

To improve the Ξ_b purity in the final $\Xi^-\ell^-$ sample, a set of five discriminating variables is used, following the method described in [15]. These variables are:

- $P_l(\Xi)$, the longitudinal momentum of the Ξ^- with respect to the thrust axis;
- $P_t(\ell)$, the transverse momentum of the lepton with respect to the jet containing the Ξ-lepton pair;
- $M(\Xi\ell)$, the Ξ-lepton invariant mass;
- $P(\Xi\ell)$, the Ξ-lepton momentum;
- $N_{\rm ch}$, the number of charged tracks in the jet.

The distributions of these variables are determined from the Monte Carlo signal data set (without polarisation) for the signal and from the set simulating processes (4) for background.

These distributions are normalized to unit area and fitted to build probability density functions (displayed in Fig. 2) for the five discriminating variables. The signal and background processes differ in each variable; however a clear separation of signal and

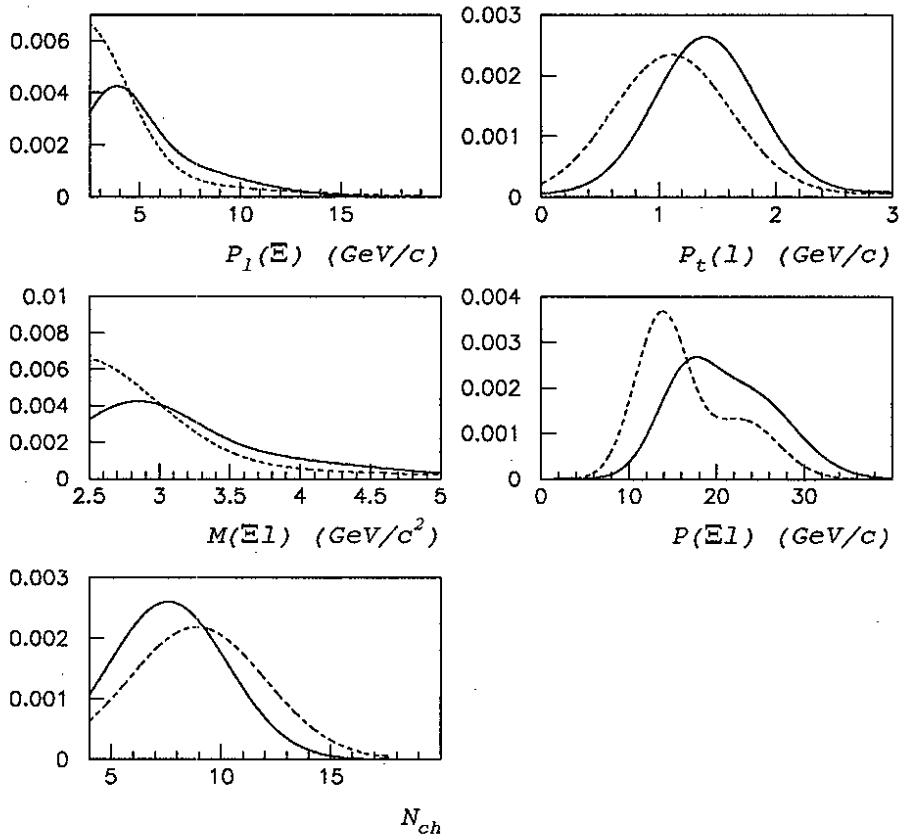

Figure 2: Probability density functions of the five discriminating variables used to build the global $x_{\rm eff}$ variable. Full lines : functions $s_i(x_i)$ for the signal Ξ_b decays; Dashed lines : functions $b_i(x_i)$ for the background.

background is not efficient in any single variable. Therefore, these five variables are combined into a single discriminating variable $x_{\rm eff}$ defined as follows [15]:

$$x_{\rm eff} = \frac{\eta \prod_{i=1}^{5} b_i(x_i)}{(1-\eta)\prod_{i=1}^{5} s_i(x_i) + \eta \prod_{i=1}^{5} b_i(x_i)}$$

where $s_i(x_i)$ and $b_i(x_i)$ are the probability density functions for the discriminating variable x_i of the signal and background Ξ-lepton events respectively, and η is the expected fraction of background same sign $\Xi^-\ell^-$ pairs. The value $\eta = 0.45 \pm 0.15$ is determined from the ratio of opposite to same sign pairs in the data; this ratio is corrected by a factor 1.2 ± 0.2 determined by the Monte Carlo to take into account the asymmetry of this background (Λ_b and B meson semileptonic decays contribute to same sign pairs and not to opposite sign pairs). The discriminating variables have been chosen to give a flat $x_{\rm eff}$ distribution for the background processes (3,4,5) of section 3, and a distribution peaked near 0 for the signal.

Fig. 3 shows the $x_{\rm eff}$ distributions for the same sign and the opposite sign Ξ-lepton pairs in data and Monte Carlo. The $x_{\rm eff}$ distribution is flat for $\Xi^-\ell^+$ pairs and peaked at zero for $\Xi^-\ell^-$ pairs coming from Ξ_b decays, allowing a clear discrimination between signal and background. In the following, all events with $x_{\rm eff} > 0.3$ are rejected. This value is chosen as a compromise between the efficiency of the analysis and the improvement of the Ξ_b purity in the same sign pairs.

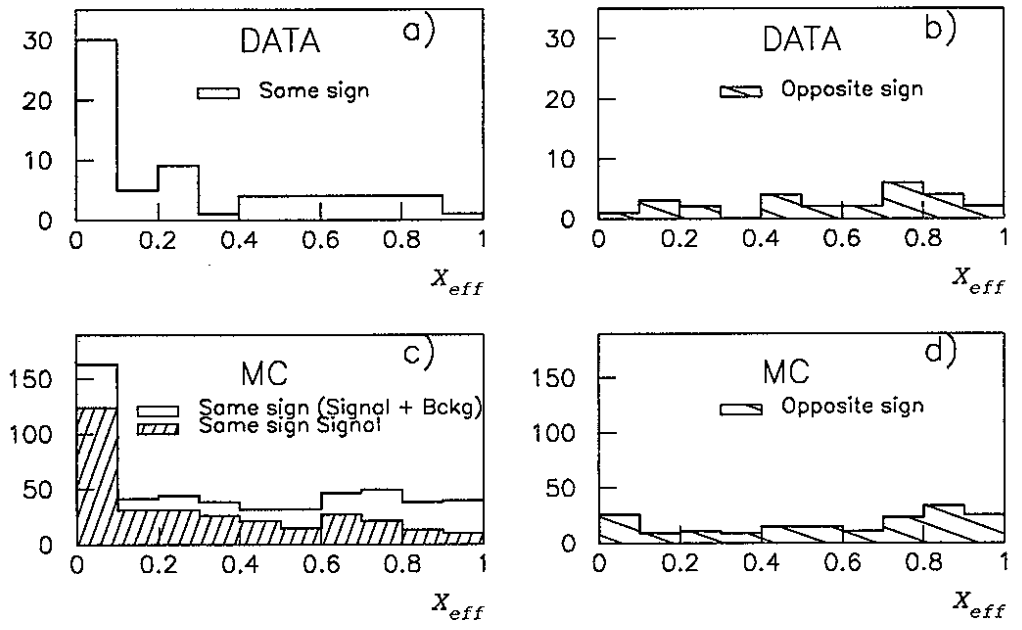

Figure 3: The $x_{\rm eff}$ distributions for Ξ-lepton pairs: (a) and (b) in data, (c) and (d) in simulated events (MC) after all selection cuts described in section 4.2 are applied except the $\Lambda\pi^-$ mass cut. In (c), the hatched histogram gives the behaviour of $x_{\rm eff}$ for the $\Xi_{\rm b}$ signal. The MC distributions are not normalised to the data.

Fig. 4 shows the $\Lambda\pi^-$ invariant mass distribution of the same and opposite sign pairs after the selection cuts (except the $\Lambda\pi^-$ mass cut), with $x_{\rm eff} < 0.3$. The peak at the Ξ^- mass is almost completely eliminated from the opposite sign pairs.

The reconstruction efficiency for $\Xi_{\rm b}$ signal events leading to $\Xi^-\ell^-$ pairs, after all selection cuts including $x_{\rm eff} < 0.3$, is estimated from the Monte Carlo simulation to be $(2.80 \pm 0.15)\%$, the quoted error being statistical only.

After all the above cuts, taking only the events for which the $\Lambda\pi$ invariant mass is within the Ξ^- mass window defined in section 4.2, there are 6 $\Xi^-\ell^+$ pairs and 44 $\Xi^-\ell^-$ pairs, of which 30 are Ξ-muon and 14 are Ξ-electron.

5 $\Xi_{\rm b}$ baryon production rate

5.1 Background estimation

In order to get the $\Xi_{\rm b}$ production rate, one has to estimate the contribution of all Ξ-lepton pairs coming from sources other than $\Xi_{\rm b}$ semileptonic decays. Applying the $x_{\rm eff}$ cut on the Monte Carlo sample, it is found that the same sign pairs not coming from $\Xi_{\rm b}$ decays are 1.4 ± 0.2 times the number of opposite sign pairs. Applying this same factor to the data, the estimation of the background contribution in the same sign pairs is 8.4 ± 3.4 events.

According to the simulation, the origin of these 8.4 background events may be detailed as follows: 3.5 events come from $\Lambda_{\rm b}$ decays, 2.5 events from B meson semileptonic decays, 1 event from the accidental combination between a lepton from a semileptonic B decay and a Ξ^- from fragmentation, and 1.4 events from the accidental combination between

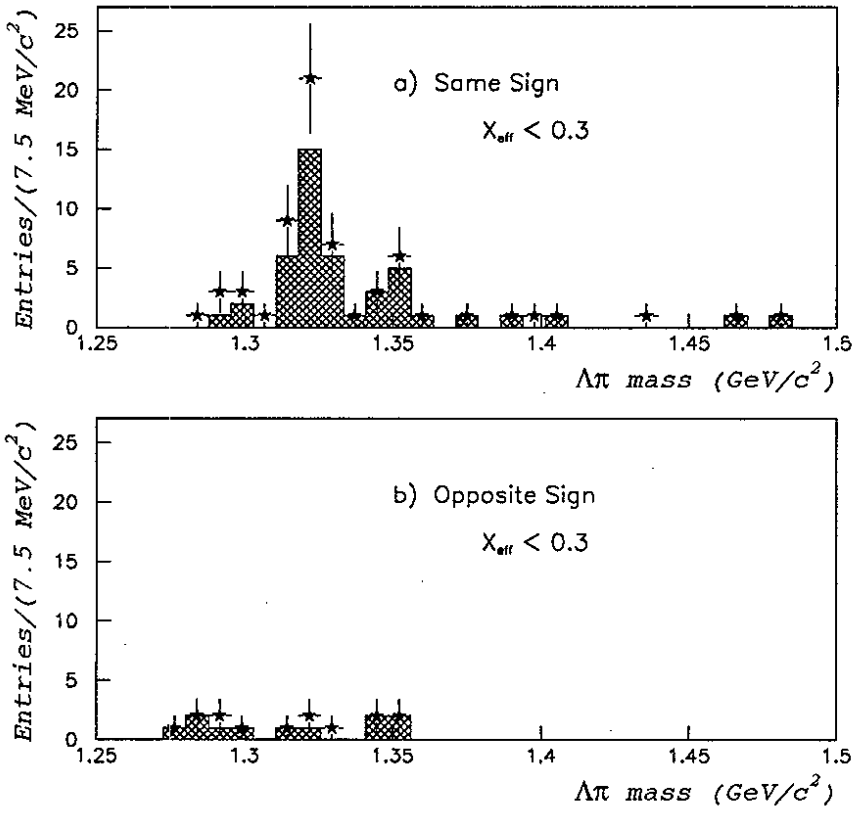

Figure 4: The $\Lambda\pi^-$ invariant mass distribution of (a) the same sign $\Xi^-\ell^-$ and (b) the opposite sign $\Xi^-\ell^+$ combinations after selection cuts and $x_{\rm eff} < 0.3$ requirement. The shaded histograms correspond to Ξ-lepton combinations where the lepton is required to have at least one three-dimensional VDET hit.

the semileptonic decay of a charmed meson or baryon and a Ξ^- from fragmentation. The contribution from fake combinations is less than 1 event and is neglected.

The background predictions from the Monte Carlo simulation may be considered reliable for processes involving charmed meson or baryon decays, which are fairly well known, and for accidental combinations. The predictions involving b hadrons are less reliable since the measurements are scarce. However two cross-checks can be done.

From the measured decay rate of B^0 and B^+ mesons giving Ξ^- :

$$\mathrm{Br}(B \to \Xi^- X) = (2.7 \pm 0.6) \times 10^{-3}\ [16]$$

and the reconstruction efficiency for this channel (0.3%), a contribution of 1.5 ± 0.5 events to the $\Xi^-\ell^-$ spectrum is expected. The B_s decay to Ξ^- is not measured; using the reconstruction efficiency for this channel (0.5%), and taking a decay rate 3 times higher than for B^+ or B^0, as suggested by the Monte Carlo, gives a B_s contribution of 0.7 ± 0.2 events. The total estimation of 2.2 ± 0.5 events coming from B semileptonic decays is consistent with the Monte Carlo expectation given above.

The Λ_b branching ratios are presently poorly known experimentally. Using the measured values:

$$\mathrm{Br}(b \to \Lambda_b) \times \mathrm{Br}(\Lambda_b \to \Lambda_c^+ \ell^- \overline{\nu}) = (1.51 \pm 0.37) \times 10^{-2}\ [17]$$

$$\mathrm{Br}(\Lambda_c^+ \to \Xi^- K^+ \pi^+) = (3.8 \pm 1.2) \times 10^{-3}\ [18]$$

and the reconstruction efficiency for this channel (1.2%), a contribution of 0.8 ± 0.3 events to the $\Xi^-\ell^-$ spectrum is expected. One should add the contribution of the four-body channel $\Lambda_b \to \Xi_c X \ell^- \overline{\nu}$, $\Xi_c \to \Xi^- X'$ for which the reconstruction efficiency is 1%; as no measurement is available, the Monte Carlo production rate of 1.2×10^{-4} is taken, leading to a contribution of 1.5 ± 0.4 events. These two Λ_b decay channels yield an estimated contribution of 2.3 ± 0.5 events.

There is no evident contradiction between the predictions of the Monte Carlo simulation and the rates calculated from available measurements. However, as the Λ_b contribution is the less well known experimentally, the prediction of 3.5 events coming from Λ_b decays will be considered as known with 100% uncertainty in the estimation of systematic errors.

Therefore the estimate of the number of background events in the $\Xi^-\ell^-$ data sample is $8.4 \pm 3.4(\text{stat}) \pm 3.5(\text{syst})$. The probability that this number fluctuates to give the 44 observed events or more is negligibly small.

5.2 Production rate

From the above discussion, the number of Ξ-lepton pairs coming from Ξ_b decays after selection cuts is $N(\Xi_b \to \Xi^-\ell^-) = (35.6 \pm 7.5)$ events.

Taking into account the $\Lambda \to p\pi^-$ branching ratio [13] and using the measured fraction of Z decays to $b\bar{b}$ relative to all Z hadronic decays, $R_b = 0.2206 \pm 0.0021$ [19], the production rate of Ξ_b baryons decaying into same sign $\Xi^-\ell^-$ pairs is:

$$\text{Br}(b \to \Xi_b)\text{Br}(\Xi_b \to X_c X \ell^- \overline{\nu_l})\text{Br}(X_c \to \Xi^- X') = (5.4 \pm 1.1(\text{stat}) \pm 0.8(\text{syst}))\ 10^{-4}$$

per lepton species, averaged over electrons and muons. This result is consistent with the one given in [6].

Table 1: Contributions to the systematic uncertainty in the Ξ_b production rate.

Source of uncertainty	Uncertainty $\times 10^4$
Contribution of Λ_b decays	0.5
Ξ_b decay model	0.4
Reconstruction efficiency	0.3
x_{eff} cut	0.3
Ξ_b polarisation	0.2
Other	< 0.1
Total	0.8

The contributions to the systematic uncertainty are detailed below, and are summarized in Table 1:

- The contribution of Λ_b decays when varied by 100% as described above gives a contribution of 0.5×10^{-4};

- A variation in the 4-body semileptonic decay rate of $\pm 20\%$ is done to estimate the effect of the Ξ_b decay model: this leads to a contribution of 0.4×10^{-4};
- The accuracy on the reconstruction efficiency due to the limited statistics of the Monte Carlo simulation gives a contribution of 0.3×10^{-4};
- The production rate has been checked to be stable, within the errors, when varying the $x_{\rm eff}$ cut from 0.1 to 0.6; the contribution to the systematic uncertainty is 0.3×10^{-4}. Varying the background fraction η in the definition of $x_{\rm eff}$ within its error has a negligible effect on the production rate;
- The effect of a possible Ξ_b polarisation is small: 100% polarisation gives a variation of 7% in the reconstruction efficiency; however the Ξ_b are certainly not fully polarised, for instance the Λ_b polarisation has been measured to be around 25% [4]; taking a 50% polarisation for the Ξ_b gives a contribution of 0.2×10^{-4}.

Other contributions to the systematic uncertainty e.g. the error on R_b or on the Λ branching ratio are negligible.

6 Measurement of the Ξ_b lifetime

6.1 Lifetime fit using Ξ-lepton combinations

The final sample of $\Xi^-\ell^-$ selected events can be used to determine the Ξ_b lifetime. The method adopted is the one used to measure the Λ_b lifetime from Λ-lepton combinations [17]. Only the important points of this method are given below.

The lepton is required to have one three-dimensional hit in at least one of the VDET layers. This implies that only data with the vertex detector in good operating conditions are used for the lifetime measurement; this restricts the data sample to 3.93 million hadronic Z decays recorded from 1991 to 1995. There are 30 $\Xi^-\ell^-$ and 3 $\Xi^-\ell^+$ events left after the $x_{\rm eff} < 0.3$ and VDET requirements (shaded histograms in Fig. 4).

The lifetime is determined by a maximum likelihood fit to the impact parameter distribution of the leptons belonging to the $\Xi^-\ell^-$ sample. The impact parameter is calculated in the plane perpendicular to the beam axis (r-ϕ plane), as the closest approach of the track to the interaction point. Then, the sign of the projection on the expected Ξ_b direction (approximated by the jet axis) is given to the impact parameter.

The experimental impact parameter distribution used to perform the fit is obtained by the convolution of the resolution function, describing the detector smearing and the error on the position of the primary vertex, with a "physics function" which is the expected signed impact parameter distribution without resolution effects. This physics function is obtained from the Monte Carlo simulation and may depend on the b quark fragmentation and Ξ_b decay models.

Five sources of leptons are considered in the fit:

- semileptonic decays of the Ξ_b baryons ("the signal"), with the unknown lifetime as a free parameter in the fit;
- semileptonic decays of the Λ_b baryon in the decay channels $\Lambda_b \to X_c X \ell^- \overline{\nu}_\ell$, followed by $X_c \to \Xi^- X$;
- semileptonic decays of B mesons giving a Ξ^- and a lepton;

- leptons from accidental correlations between a Ξ^- from fragmentation and a lepton from the semileptonic decay of a b meson or baryon;
- leptons from accidental correlations between a Ξ^- from fragmentation and a lepton from the semileptonic decay of a c meson or baryon.

The contribution of fake combinations is small enough to be neglected in the fit.

The overall background contribution is estimated from the 3 opposite sign events in the data, corrected by the background asymmetry factor of 1.4 defined in section 5.1. This gives 4.2 ± 2.4 events, which is $(14\pm8)\%$ of the total. Table 2 shows the individual fractions for each background channel.

Table 2: Background contributions to the lifetime fit. The D meson lifetime is a weighted average of the D^0, D^+ and D_s lifetimes.

Background channel	Background fraction %	Average lifetime (ps)	References for lifetimes
$b\rightarrow \Lambda_b \rightarrow \ell\Xi$	6.0	1.20 ± 0.20	[20]
$b\rightarrow B \rightarrow \ell\Xi$	4.0	1.55 ± 0.10	[21],[22]
$c\rightarrow D \rightarrow \ell$, Ξ fragmentation	2.5	0.65 ± 0.05	[13]
$b\rightarrow B \rightarrow \ell$, Ξ fragmentation	1.5	1.55 ± 0.10	[21],[22]

The resolution functions (described by two Gaussians) are those used for the Λ_b lifetime determination in Λ-lepton combinations [17], with the same error rescaling factor of 1.3 on the data sample to account for the differences with the Monte Carlo error simulation.

The "physics functions" are parameterised for each lepton source by the use of one exponential for the negative values of the impact parameter and two exponentials for the positive values.

The unbinned maximum likelihood fit to the signed lepton impact parameter distribution for the 30 $\Xi^-\ell^-$ events yields the Ξ_b lifetime :

$$\tau_{\Xi_b} = 1.35^{+0.37}_{-0.28}(\text{stat})\ \text{ps}$$

Fig. 5 shows the measured impact parameter distribution, together with the result of the fit and the contribution of the background.

6.2 Systematic uncertainties

The contributions from the main sources of systematic uncertainties affecting the present measurement are investigated and their respective contributions are summarized in Table 3.

Resolution function: the resolution function has been changed within the statistical error of its parametrisation, and the rescaling factor of 1.3 applied for the data has been varied from 1.0 to 1.7. This gives a systematic uncertainty of ± 0.10 ps to the lifetime.

Impact parameter: in the data, the occurence of large impact parameter events ($\delta > 0.1$ cm) is higher than in the Monte Carlo sample. To take this effect into account,

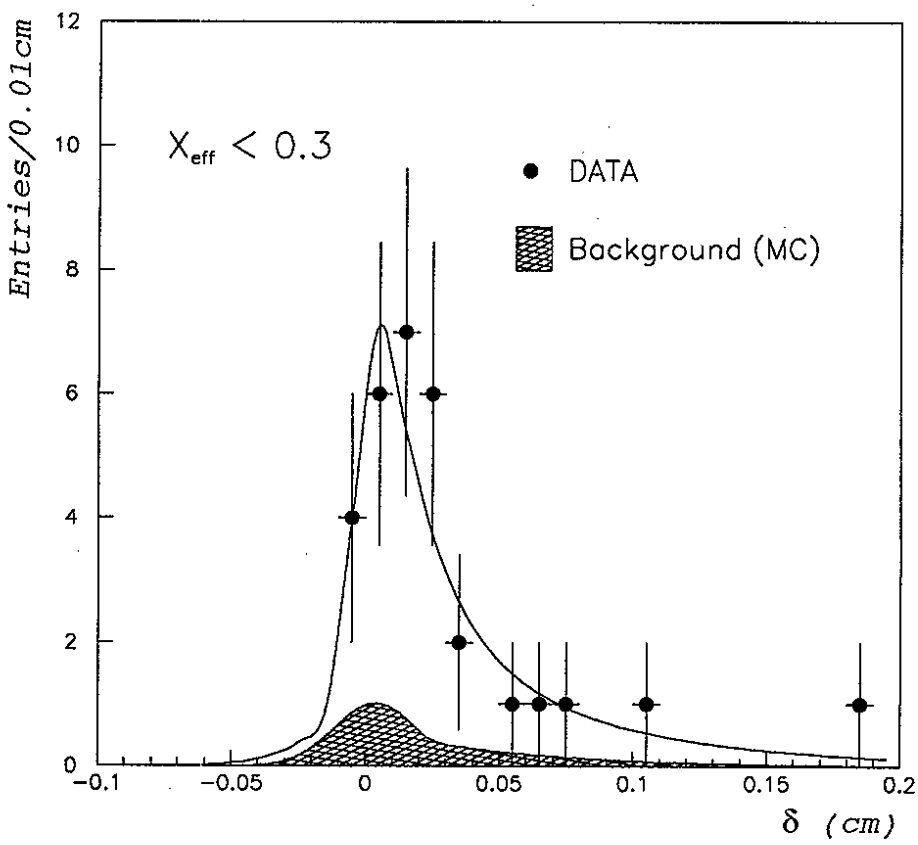

Figure 5: Impact parameter distribution of the selected $\Xi^-\ell^-$ events. The solid line is the result of the maximum likelihood fit.

the lifetime fit has been tried with a modified version of the resolution functions including a third Gaussian with a much larger resolution. This leads to a systematic uncertainty of $^{+0.00}_{-0.08}$ ps in the lifetime determination.

Overall background rate: the overall background contribution has been varied within its 60% relative uncertainty; this gives a ± 0.05 ps variation on the lifetime.

Background composition: varying the background components within their statistical error gives a ± 0.05 ps variation of the lifetime. The effect of the errors on the lifetimes of the different background components is negligible.

Physics function: the uncertainty in the parametrisation of the physics functions is due to the limited Monte Carlo statistics and leads to a systematic uncertainty of ± 0.05 ps on the lifetime measurement.

Effect of the $x_{\rm eff}$ cut: The lifetime measurement has been checked to be stable, within the errors, when varying the $x_{\rm eff}$ cut from 0.1 to 0.6; the contribution to the systematic error on the lifetime is ± 0.05 ps.

Effect of Ξ_b polarisation: The fit has been done on the two Monte Carlo "signal" samples generated with 100% polarisation and no polarisation. The difference on the fitted lifetime between these two extreme cases is 0.04 ps. Assuming a 50% polarisation for the Ξ_b gives a ± 0.02 ps variation on the lifetime.

Table 3: Contributions to the systematic uncertainty in the Ξ_b lifetime measurement.

Source of uncertainty	Uncertainty (ps)
Resolution function and error estimation	± 0.10
Impact parameter	$^{+0.00}_{-0.08}$
Overall background rate	± 0.05
Background composition	± 0.05
Physics function	± 0.05
$x_{\rm eff}$ cut	± 0.05
Ξ_b polarisation	± 0.02
Ξ_b decay model	± 0.02
Other	± 0.05
Total	$^{+0.15}_{-0.17}$

Effect of Ξ_b decay model: A variation of $\pm 20\%$ of the proportion of 4-body decays, as already used in the estimation of systematic effects in the production rate, gives ± 0.02 ps variation on the lifetime.

The same analysis has been applied to two Monte Carlo samples of Ξ_b baryons with generated lifetimes of 1.5 and 1.0 ps. The fitted results are $1.48^{+0.10}_{-0.08}$ ps and $1.10^{+0.17}_{-0.15}$ ps, respectively, consistent with the input values.

As the Ξ_b lifetime uncertainty is dominated by the available statistics, other minor sources of systematic errors such as b quark fragmention are not investigated in detail. From the studies done for the Λ_b lifetime in Λ-lepton combinations [17] they should not exceed 0.05 ps.

The final result for the Ξ_b lifetime is:

$$\tau_{\Xi_b} = 1.35^{+0.37}_{-0.28}(\text{stat})^{+0.15}_{-0.17}(\text{syst})\ \text{ps}.$$

This value is consistent with the one given in [6].

7 Conclusion

A search for events containing a Ξ baryon and a lepton of the same charge in the same event hemisphere has been performed in a data sample of 4,188,000 hadronic Z decays. An excess of 35.6 ± 7.5 events is found; it is interpreted as evidence for the semileptonic decay of the strange b baryon Ξ_b and yields the following product branching ratio:

$$\text{Br}(b \to \Xi_b) \times \text{Br}(\Xi_b \to X_c X \ell^- \overline{\nu_l}) \times \text{Br}(X_c \to \Xi^- X') = (5.4 \pm 1.1(\text{stat}) \pm 0.8(\text{syst}))\ 10^{-4}$$

per lepton species, averaged over electrons and muons.

Using only the events where the lepton has a hit in the silicon vertex detector, an unbinned maximum likelihood fit to the impact parameter distribution of the leptons gives the following

Ξ_b lifetime :

$$\tau_{\Xi_b} = 1.35^{+0.37}_{-0.28}(\text{stat})^{+0.15}_{-0.17}(\text{syst})\ \text{ps}.$$

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